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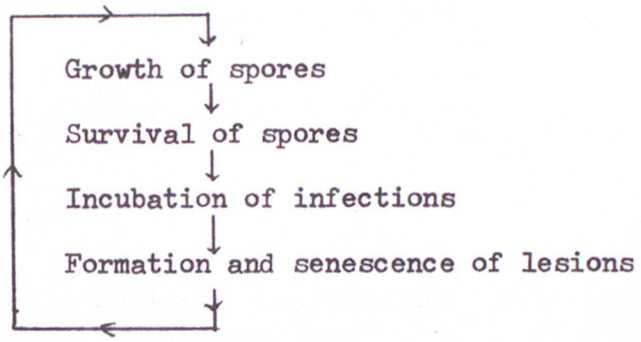
AGRICULTURAL MEMORANDUM 899

BLIGHT: A COMPUTER MODEL RELATING THE PROGRESS OF POTATO BLIGHT TO WEATHER

1. INTRODUCTION

The purpose of BLIGHT is to marshal all the known relationships between potato blight and its environment in a way that will allow the development of the disease to be calculated through the season.

The disease progresses through many generations during a season and environmental factors control its development at every stage of the life cycle. The stages in the development of the disease that are explicitly modelled by BLIGHT are:-



This is a great simplification of the full life cycle of the disease and such important processes as detachment and spread of spores, their deposition on the leaf area at risk and their germination are not explicitly modelled; they are simply assumed to happen.

The input to the model is hourly weather data and information about the variation of haulm growth with time. The model assumes that there is always at least one lesion that is capable of sporulating, given the right conditions, and calculates the development of the disease from hour to hour. At the end of each model day it prints out the number of lesions sporulating, the number of spores released and the number of new infections. These numbers are not, of course, the numbers that would be produced in a real field of potatoes but their variations through the season mirror developments in the real field.

2. HOURLY WEATHER DATA AND CONDITIONS IN THE CROP

Every hour the computer reads the air temperature and dew point in the thermometer screen and is told whether or not there has been rain, drizzle, snow, hail or fog during the past hour. These data are used to determine whether the foliage is wet or dry and to estimate the humidity in the crop canopy. The measure of humidity used in the model is dew point depression; its relationship to relative humidity is shown in figure 1.

It has been shown by Hirst and Stedman (1960) that the development of the potato haulm has a considerable influence on the humidity within the canopy. They defined the following foliage categories:-

1. Plants easily distinguishable from a distance as individuals. Foliage meeting neither in rows nor across them.

2. Foliage meeting in but not across rows, stems erect.

3. Foliage meeting both in and across rows and forming a complete canopy, stems erect.

P. Indicates prostrate stems with erect side branches and is combined as 2P or 3P to indicate both the total amount and state of foliage.

The data presented by Hirst and Stedman are not completely consistent from year to year but may be interpreted to give the following relationships between dew point depression in the crop canopy (CDPD) and dew point depression in the thermometer screen (DPD).

Crop stage 1	CDPD = DPD
Crop stage 2	CDPD = 0.9 x DPD
Crop stage 2P or 3	CDPD = 0.75 x DPD
Crop stage 3P	CDPD = 0.5 x DPD

Leaf wetness is not directly observed, it must, therefore, be inferred from other observations. Leaves are assumed to be wet in any of the following circumstances:-

If there is rain, hail, snow, drizzle or fog at the time of observation.
If there has been rain, hail, snow or drizzle during the past hour.
If, during the night, the dew point depression in the screen is less than 0.5°C. (dew is assumed to be present)
If the leaves were wet the previous hour and dew point depression in the crop is less than 1.6°C (≡ 90% relative humidity).

The development of potato blight is much less sensitive to temperature than to humidity or leaf wetness, therefore, temperature in the screen is considered to be a sufficient representation of temperature in the crop canopy.

3. THE GROWTH OF SPORES

Only qualitative information about the rate of formation and abundance of spores is available. Crosier (1934) states:-

"In saturated atmospheres, sporangia formed on both tubers and leaves at [illegible]°C to 26°C but in no case at 1° to 2° or 27°. Although aerial mycelium developed abundantly at 23° to 26°, the sporangium production was very slight, and it is doubtful that the limited number of spores would be a serious source of inoculum for field infections. Temperatures of 18° to 22°C were optimum both for rapidity and for intensity of sporulation. Sporangia commonly appeared within 8 hours and were abundant in 14 hours. At 9° to 15°, sporangia were fairly numerous in 24 hours and were plentiful in 48 hours. Moreover, infected material exposed to this temperature range continued to produce sporangia over a period of a week or ten days. At temperatures as low as 3°, only a few sporangia were present in six days."

For the computer model the above description of the formation of sporangia must be translated into an equation relating their formation to temperature. The equation used and the relationship it specifies is shown in figure 2. The model takes 1 hour at 21°C as 1 unit of spore growth. It can be seen from figure 2 that 1 hour at any other temperature will provide less than 1 unit of spore growth. One hour at 12°C, for example, gives 0.5 units of spore growth. In accord with Crosier's observations the model forms the first spores when 8 spore growth units have been accumulated and maximum production is reached after 14 units. Production between 8 and 14 units is assumed to be linearly related to the accumulation of growth units.

The above describes the production of spores in a saturated atmosphere. Before spore growth units are summed and translated into spore production they must be adjusted for the humidity in the crop. No quantitative data is available on the effect of humidity on spore production. However, Crosier (1934) says "Sporangia never formed in an atmosphere of loss than 91 per cent relative humidity ..... and .... sporangia formed more quickly and abundantly in a saturated atmosphere

at 6°C than in an atmosphere of 91 per cent relative humidity at 21°C. In a nearly saturated atmosphere, 97 per cent relative humidity, the sporangium formation was never abundant. The results of many tests show that abundant production of sporangia can be obtained only in a completely saturated atmosphere." In view of Crosier's observations the thermal units for spore growth are multiplied by the factor (1-0.65 x dew point depression in the canopy). The dew point depression in the canopy is assumed to be zero if the leaves are wet, otherwise it is related to the dew point depression in the screen and the crop stage as stated in paragraph 2. This factor has the effect of relating production of sporangia almost linearly to relative humidity and reducing it to zero when the relative humidity in the canopy is about 90.5%.

A period of spore growth starts when the dew point depression in the canopy (CDPD) falls below 1.6°C or when the growth of other spores is completed if CDPD remains below 1.6°C. The growth period continues until CDPD exceeds 1.5°C during the day (periods of low humidity during the night are assumed to suspend growth but not to terminate it) or after 48 hours, which ever is sooner. Since the CDPD may oscillate about 1.5°C during the day there may be more than one growth period in 24 hours but only those providing more than 8 growth units can produce spores.

4. THE SURVIVAL OF SPORES

The death rate of fully grown spores is dependent on temperature but other than the statement by Crosier that "The loss of viability at 25°C and 30°C was more rapid than at 20°C" no information is available on the relationship between temperature and death rate. Crosier does, however, give detailed data on dependence of the rate of loss of viability of spores on relative humidity at 20°C. Humidity is almost certainly more important than temperature for the survival of spores in the UK and in view of the dearth of information on the effects of temperature on spore mortality, temperature is ignored and Crosier's relationship between humidity and spore mortality is assumed to apply at all temperatures. The equation used by the model to calculate spore mortality is shown in figure 3 with a plot of crosier's observations. Once spores have started to germinate they are completely dependent on leaf wetness for survival. The model assumes that 1 hour with the leaves dry is sufficient to kill all germinating spores.

5. DISPERSION OF MATURE SPORES

There is some uncertainty about the maturation of spores and their release. Hirst (1953) observed the diurnal variation of the concentration of airborne spores. He found that the rapid release of spores began at about 0700, spore concentration reached a peak at 1000 and then decreased fairly uniformly to become negligible by about 1800. He states that "Liberation coincides with rising temperature and the disappearance of dew and raindrops from the leaves of potential hosts" but he also says "Rain and strong winds apparently modify this periodicity slightly but seem not to be the major controlling factors". It has been suggested by de Bary (1887) that spore discharge occurs with the hygroscopic twisting movements of sporangiophores are exposed to rapidly changing humidity. Hirst's observed diurnal variation of mean counts of airborne spores are consistent with de Bary's assumption but there is some doubt whether or not spores are released when the humidity remains high during the day or when it drops during the night. Each of these processes could have a considerable influence on the progress of the disease. If spores are not released when the humidity is high this could limit the spread of the disease in wet weather. De Weille (1963) says that spores require a period of maturation in daylight, while they are still attached, before they can germinate, therefore, spores released at night will not cause infection.

The first version of BLIGHT assumes that spores are released according to the mean diurnal pattern reported by Hirst regardless of the weather, but later versions will test the assumptions that a. spores are released only during the day when the

relative humidty is less than 90% and decreasing and b. spores are released at any time if the relative humidity is less than 90% and decreasing.

The proportion of available spores released each hour through the day has been calculated from Hirst's data and is shown in figure 4.

6. GERMINATION OF SPORES AND INFECTION OF THE HOST

In the field this is a complex, multi-stage, process. Spores may germinate directly, produce a germ-tube, penetrate the host and produce infection but the optimum temperature for this process is 24°C and even at that temperature there is only 10% germination after 16 hours of continuous leaf wetness (Crosier 1934). Under UK conditions indirect germination is much more efficient. Each spore produces zoospores which, after a period of mobility, encyst, grow a germ-tube, penetrate the host and produce infection. The optimum temperature for indirect germination is 15°C but it can proceed with reasonable efficiency at 3°C and probably at even lower temperatures. Every stage of the germination and infection process requires the presence of free water on the plant surface.

An attempt was made to model these processes using the relationships established by Crosier but it was found that the inclusion of these steps in the program led to instability. A change of 1 or 2 hours in inferred leaf wetness would occasionally switch the prediction from heavy infection to zero infection during a particular wet period. Much more consistent results were obtained by assuming that when conditions are suitable for the growth and survival of spores they are also suitable for germination and infection. The latter two processes are, therefore, not explicitly modelled.

7. INCUBATION OF INFECTIONS

An incubation period is required, after a potato plant has been infected, before a lesion capable of sporulating is formed. Crosier (1934) showed that the incubation period is dependent on temperature and has a minimum length, about 75 hours, at 21°C. The thermal unit for lesion development in the model has been chosen as 1 hour at 21°C and incubation is complete when the sum of incubation units exceeds 75. At temperatures other than 21°C incubation takes longer so 1 hour at another temperature counts less than 1 incubation unit. The relationship assumed between incubation units and temperature is based on Crosier's observations and is shown in figure 5.

8. DEVELOPMENT OF LESIONS

When incubation is complete a lesion capable of sporulating is produced. The lesion extends and is able to produce a greater number of spores but after a time the middle of the lesion dies and its capacity for spore production decreases and eventually ceases. This is simulated in BLIGHT by not allowing all simultaneous infections to produce sporulating lesions simultaneously. The proportion of infections that result in lesions is 0 until the sum of incubation units reaches 75 and is then increased linearly to 1 as the sum of incubation units rises to 150. This results in an increase of potential spore production over a period of 3 to 5 days after the formation of the first lesion of a new generation. A typical example of the way potential spore production changes with time is shown in figure 6.

There is some uncertainty about the length of time that a lesion can continue to produce sporangia. Waggoner (1968) assumes that the productive period of a lesion is temperature dependent and is equal to the incubation period, ie it is calculated in the same thermal units. This is an attractive simplification from the point of view of the programmer but implies that a lesion will remain active for longer at 25°C than at 21°C which is not in accord with the few recorded observations of lesion sporulation activity and progression that are available. Crosier's (1934)

paper implies that a lesion will produce sporangia for about 10 days at 9°C, 7 days at 15°C and for a shorter period at 18° to 22°C. If the relationship between active lesion life and temperature is assumed to be linear the above data imply that at 0°C active lesion life is 14.5 days and at 29°C it is zero. The observational evidence suggests that a temperature higher than 29°C is required to cause rapid death of the pathogen in a lesion, therefore, as a compromise between the few pieces of evidence available it is assumed that the productive life of a lesion is related to temperature by the equation

$$L = 320 - 10\ t \text{ for } 0 \leq t < 32\ ^{\circ}C$$

$$L = 320 \text{ for } t < 0^{\circ}C \text{ and } L = 0.1 \text{ for } t \geq 32^{\circ}C$$

Where L is the productive life in hours
and t is the temperature in degress Centigrade

Units for lesion senescence are defined as 1/L and the model assumes that a lesion becomes incapable of sporulating when the sum of senescence units, from the start of its productive life, exceeds 1. This procedure results in a sudden cessation of lesion activity, as shown in figure 6, which is not very realistic and there are plans for bringing activity to a more gradual end.

Not all lesions have a short productive life, those that form on stems, rather than leaves, remain active very much longer and provision has been made in the programe to allow any desired proportion of lesions to remain active from the time of their formation until the end of the season.

9. THE FLOW CHART FOR BLIGHT

The foregoing paragraphs describe the way BLIGHT deals which each stage of the life cycle of potato blight. The way that these stages are interconnected in the model is shown by the flow chart (figures 7a to 7c). The chart is read by beginning at START and following the arrowed paths. When a diamond is reached the path to be followed depends on the answer to the question in the diamond. The computer will meander through the flow diagram, carrying out all instructions until 2300 on the last day of the blight season or until it calculates that the potato haulm has been completely destroyed.

10. PROGRAM OUTPUT

'There is no more common error than to assume that, because prolonged and accurate mathematical calculations have been made, the application of the results to some fact of nature is absolutely certain'.

A N WHITEHEAD

The above quotation should be kept in mind when reading the remainder of this paper. It would be tedious in the extreme to qualify the description of each prediction by BLIGHT with statements of uncertainty; but such statements must be assumed. In particular the numbers of spores and infections predicted should be regarded as index numbers that have some unknown, and perhaps variable, proportionalities to the numbers in the real world.

The output from the BLIGHT program for Elmdon (Birmingham Airport) in 1978 is shown in figures 8a to 8c. It was assumed that there was one lesion active at the start of the season and that, given suitable weather, it was able to produce spores at any time. Hence IESPOR (the number of lesions capable of sporulation) was always at least 1. The program calculated the number of spores released by an active lesion each day (JSPORE) and the number of new infections that resulted (INFECT). After a period of incubation, determined by temperature, the infections produced new active lesions ie IESPOR increased. The majority of lesions remained active for only a few days but a small proportion, determined by the parameter STEM (set

at 0.1 for this run) were assumed to remain active throughout the remainder of the season. These processes are well illustrated in figure 8b during the period 9 July to 22 July. At the start of this period LESPOR was influenced by the infections that occurred from 2 to 5 July so that is is not clear when the 4181 infections of the 9 July started to produce active lesions; it was probably on 14 July. It is quite clear, however, that the number of active lesions produced by those infections increased over the next few days to reach a maximum on 19 July and that the majority ceased to be active after the 21 July.

The calculations of the next few days illustrate the vital importance of the timing of weather periods that favour infection. A major infection period occurred on 23 July when 572 lesions were active; if that infection period had taken place just 2 days earlier 4335 lesions would have been active and the resultant level of infection would have been greater by a factor of 7.5. Accurate determinations of lesion life are clearly necessary for proper modelling of the disease.

It is notable that even in a year favourable to blight development (1978 gave the most widespread field occurrence since 1968) new infections took place on only a minority of days and that the disease passed through many generations during the season. The implication of these results for chemical control of blight will be discussed later.

The final column of output from the model is the natural logarithm of the total number of lesion produced from the start of the season; this has been found to give a useful measure of the progress of the disease.

11. VERIFICATION OF THE MODEL

11.1 Data used for verification

The records of blight made by the Plant Pathology Laboratory (now The Harpenden Laboratory) for the 13 years 1958 to 1970 were used to test and calibrate the model. These records generally show only the date of the first outbreak of blight in fields fairly close to each synoptic meteorological station. An example of the type of information available is shown in figure 9. It can be seen that there is often a considerable variation in the outbreak dates across the midlands.

For the years 1958 to 1970 hourly meteorological data are recorded on magnetic tape for only 2 of the stations in the midlands, Elmdon and Waddington, so that no individual blight calculations could be made for the other stations. In order to use as much of the plant pathologist's data as possible BLIGHT predictions using weather data from Elmdon and Waddington were compared with the mean of the outbreak dates at the 7 midlands stations each year. A similar procedure was followed for south west England where calculations from weather data for Plymouth were compared with average outbreak dates in fields near Chivenor, Exeter, Plymouth and St Mawgan. For verification in north Wales only data from Valley were available.

11.2 'Tuning' the model

The values of most of the constants in the model were predetermined from laboratory data but 5 parameters can be set to arbitrary values they are:-

a. INOCULUM ie the number of lesions active at the start of the season, this was initially set to 1 and it has not been necesssry to change it.

b. MAXIE, which is the number of lesions required to completely destroy the haulm, this has been maintained constant at 2×10^9.

c. The proportion of spores released that result in infections was set to 0.1 and has been kept constant for all runs.

d. MAXSPL, the maximum number of spores that can be produced by a lesion in 1 day under ideal weather conditions, was adjusted to ensure that in 1958 when complete haulm destruction was reported the model predicted it at about the correct date. The value of MAXSPL deduced in this way was 300 and that figure was used in all years.

e. The proportion of lesions that have a long productive life, STEM, was set at 0.1 for all the verification runs of the program. This was not an arbitrary decision and the effects of changing STEM will be discussed later.

With the above parameters maintained constant the program was run for the years 1958-70 and the calculated value of $\log_e$ (lesions) was noted on the mean outbreak date each year. These numbers were averaged for the 13 years. The procedure was then reversed and the day on which the calculated $\log_e$ (lesions) reached the average was taken as the predicted date of outbreak for that year.

11.3 Comparison of dates of observed and predicted outbreaks

The procedure described above ensures that, over the 13 years considered, the average predicted date of outbreak of blight is very close to the average observed outbreak. The test of the model's performance must, therefore, be the correlation between predicted and observed outbreak dates in individual years. This is shown in table 1.

TABLE 1 PERFORMANCE OF 'BLIGHT' FOR THE 13 YEARS 1958-1970

		Midlands	SW England	N Wales
a.	Standard deviation of actual outbreak dates (days)	17.59	11.96	10.64
b.	Standard deviation of predicted outbreak dates (days)	13.57	11.72	11.54
c.	Standard deviation of difference (a - b) (days)	9.58	6.72	7.95
d.	Coefficient of correlation between actual and predicted dates	0.84	0.84	0.76

The correlations indicate that the model shows significant skill in predicting blight outbreaks.

The combined results for the 3 regions are shown graphically in figure 10. The majority of predicted dates are within 10 days of the observed dates but one prediction for the midlands (indicated by an arrow in figure 10) has an error of 22 days. The calculated progress of blight for that year is shown in figure 11. The average reported outbreak date in the midlands was 20 July but for the next 15 days the weather was not favourable for blight so that a delay in taking protective measures would not have been serious.

12. THE EFFECT OF LESION LIFE ON THE PROGRESS OF THE DISEASE

Figure 12 shows how the length of time that lesions can produce spores effects the calculated progress of the disease through the season. In a wet summer (1958) infection periods occurred so frequently that an extension of the active life of lesions made little difference to the rate of progress of the disease. While in a dry summer (1959) a short lesion life allowed the disease to 'burn out' so that when infection periods did occur later in the season the disease had very little on which to build.

The curve for short lesion life in 1959 was much closer to the observed progress of the disease than that for long life. It was, however, found that a proportion of lesions had to be given a long life to reproduce the observed progress of the disease in other dry summers. When that was not done the calculated increase of infection after a dry spell was too slow. The simulations carried out to date do not allow a precise determination of the proportion of lesions with long active lives but it is probably between 1% and 10%. Figure 12 also shows the calculated progress of the disease in 1959 when 10% of lesions were allowed to remain active until the end of the season. The indication from BLIGHT that some lesions must have a long active life is in agreement with observational evidence of the importance of stem lesions for the survival of blight through dry periods presented by Clayson and Robertson (1956).

13. DISCUSSION

13.1 BLIGHT makes use of relationships between critical stages in the life cycle of potato blight and its environment. Those relationships were investigated in the laboratory under controlled, usually steady, conditions but their use in the field with only routine weather observations and a very simplified life cycle of potato blight has produced realistic computations of the progress of the disease. Only 2 of the many parameters in the model could not be set either from laboratory results or by consideration of the size of numbers it would be convenient to handle. The fact that it was possible to bring the predictions of the model so close to the observed progress of blight by the adjustment of only 2 parameters suggests that the most important influences of weather on the progress of the disease are well represented in the model.

13.2 The importance of early season blight periods

In the past there has been much discussion between meteorologists and plant pathologists about the significance of early season blight periods determined by either the Beaumont or L P Smith criteria. The model shows that they are of great importance in building up the disease to a point at which one further blight period is able to boost it to a level that can be detected by routine field observations.

13.3 Graphical representation of blight levels

The key used by plant pathologists to report the level of potato blight in the field is shown in figure 14. The key over-estimates the percentage of haulm actually affected by blight during the early stages. When these observations are plotted on a linear scale of percentage infection against time, as they often are, the curve usually shows a very slow increase of infection for a few weeks after the outbreak and then a rapid rise from about 5% to 75%. Figure 13a shows this apparent behaviour of the disease: it is almost entirely due to the method of recording and plotting. The plot of the same data on a logarithmic scale in figure 13b suggests that the infection multiplied fairly steadily through the season with no great upsurge in the second week of September.

13.4 Possible uses for BLIGHT

If the construction of BLIGHT is to be more than an interesting academic exercise, ways must be found to employ it in the development of methods to control potato blight in the field.

Most fungicides used for blight control are not curative, they merely reduce the amount of new infection for a period of 1 or 2 weeks while they remain on the leaves. Since the haulm grows during the season new unprotected leaves are continually produced. To maintain protection against the disease most major growers of potatoes apply protective sprays routinely at intervals of about 10 days from the beginning of July until the end of September.

BLIGHT indicates that the disease must pass through several generations before it reaches a damaging level in the crop and that it makes rapid progress only when an infection period occurs while all the lesions of the previous generation are able to produce spores. The period for which protection is required starts about 4 days after an infection day and lasts about 4 to 7 days. This allows a strategy of post infection spraying to be followed. Under such a system a grower would be notified when an infection day had occurred and would have 3 days in which to spray. His crop would then be protected for about 10 days. The crop would not be protected against the first infection period to occur more than 10 days after his spray but by that time the majority of lesions produced by the previous generation would be inactive so that the new blight period would not produce a large increase in the level of the disease. It would, however, be a signal for the grower to apply another spray. Preliminary calculations show that, if such a spray programme could be fully carried out, it would achieve adequate disease control with only 50% of the spray applications that are used in the 10 day routine spray schedule. However, the ground is usually wet after a blight period and there may be occasions when it would not be possible to spray within 4 days of infection. In those circumstances another infection period before a spray had been applied would allow the disease to make rapid progress. If weather and soil conditions for spraying could be specified it would be possible to adapt BLIGHT to calculate the probability of that happening.

The ability of BLIGHT to identify major infection periods could be used to investigate the possibilities of pre-infection spraying based on weather forecasts. A preliminary investigation of the synoptic situations that produced major infection periods at Elmdon in 1978 showed that most occurred when either a slow-moving depression was centred near the midlands or when a quasi-stationary front affected the area. If the requirement for such conditions is confirmed by a more thorough analysis, quite reliable forecasts of blight weather may be possible in sufficient time for growers to take action. Given forecasts of moderate reliability, ie 50% of infection days correctly forecast and 50% of positive forecasts not followed by a blight period, a spray schedule using a combination of forecast based applications and post-infection applications, with the restriction that no two sprays are applied within 7 days, has been calculated to control potato blight as well as routine sprays at 10 day intervals at Elmdon in 1978. The forecast based system required little more than half the number of spray applications of the routine system.

14. CONCLUSIONS

A computer model based on laboratory studies of the effects of the environment on the development of potato blight has produced realistic predictions of the progress of the disease in the field when supplied with only standard weather observations.

The model could be used to identify synoptic situations that promote blight and to evaluate various control strategies, including the use of weather forecasts.

The model strongly suggests that potato blight must pass through many generations before it achieves a damaging level in the crop so that the mistiming or omission of two or three control sprays during a season does not carry a severe penalty.

ACKNOWLEDGMENTS

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Any comments or suggestions on this paper should be referred to the author.

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Figure 1

The relationship between dew point depression and relative humidity

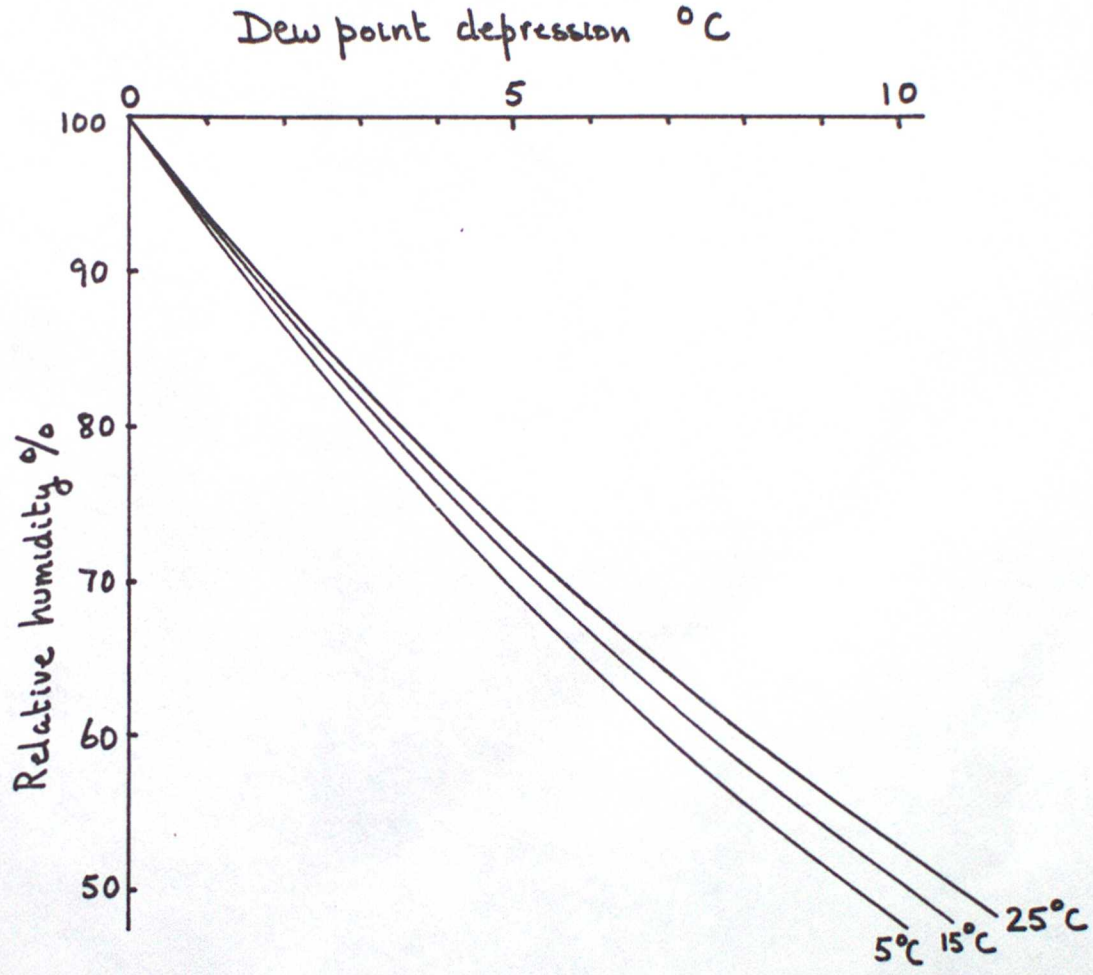
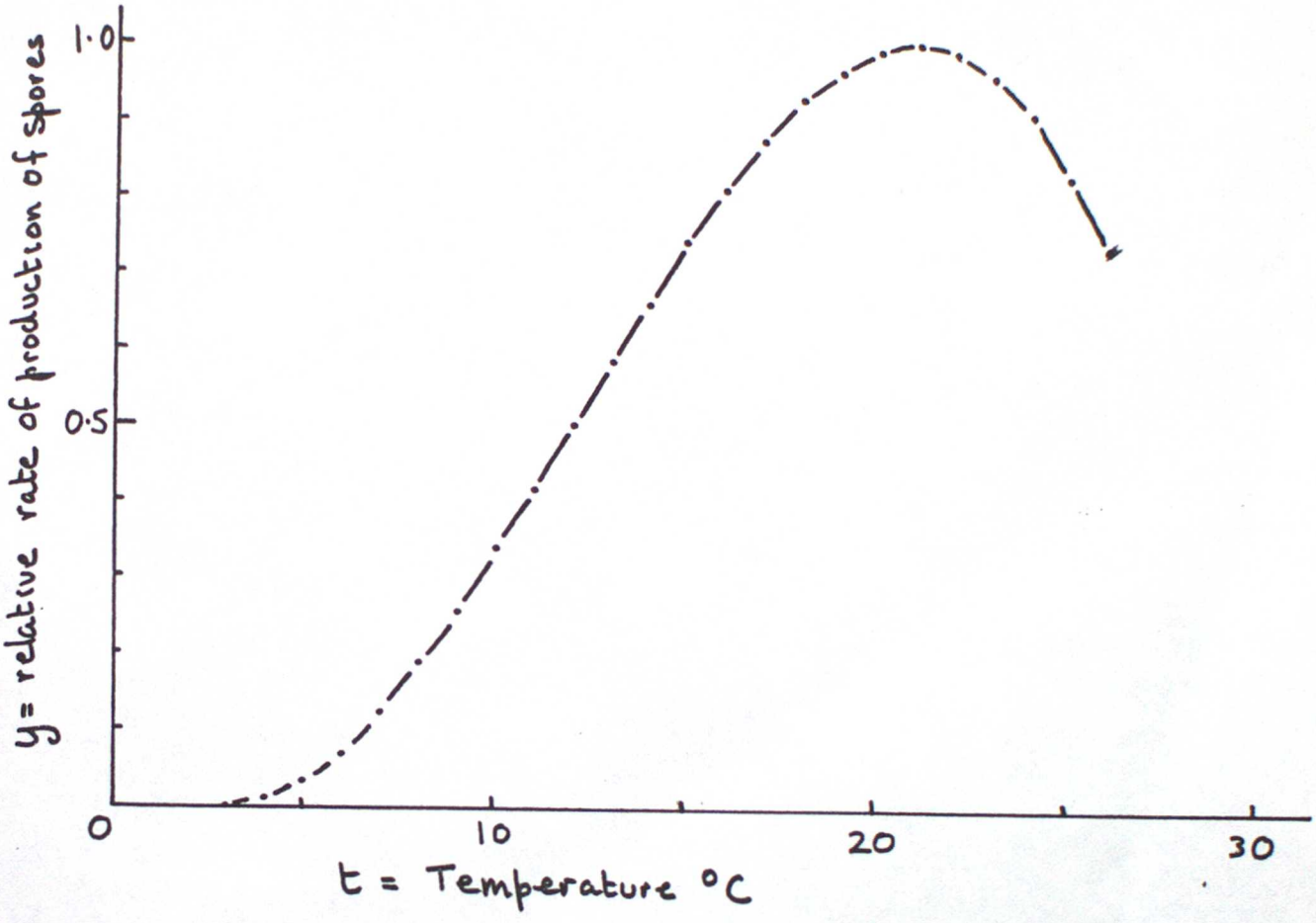


Figure 2

The relationship between the rate of production of spores and temperature



$$y = \frac{(t-3)^2}{108} - \frac{(t-3)^3}{2916} \qquad 3 \leq t \leq 26$$

If $t < 3$ or $t > 26$ $y = 0$

Figure 3

The relationship between spore survival and dew point depression

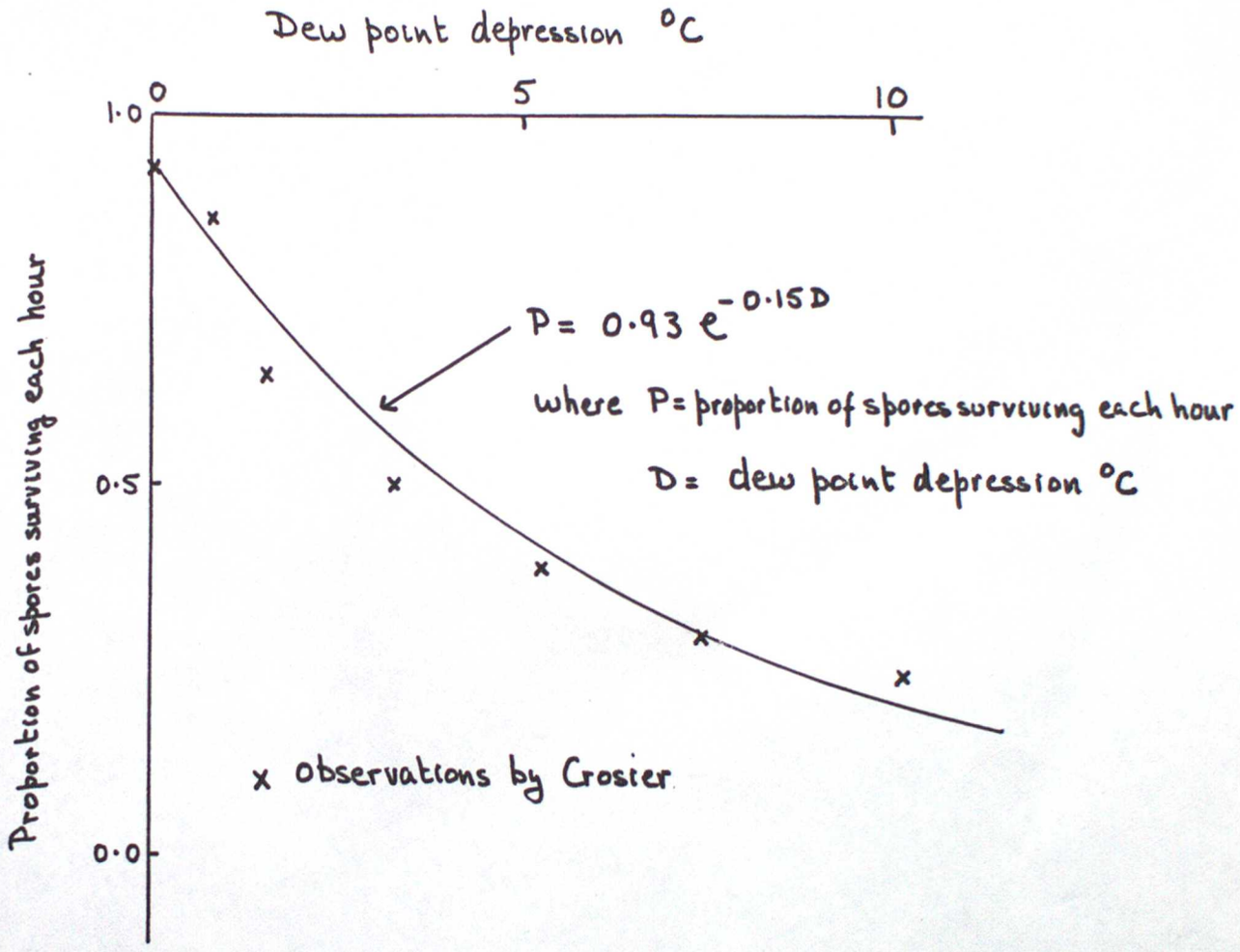


Figure 4

Proportion of available spores released each hour

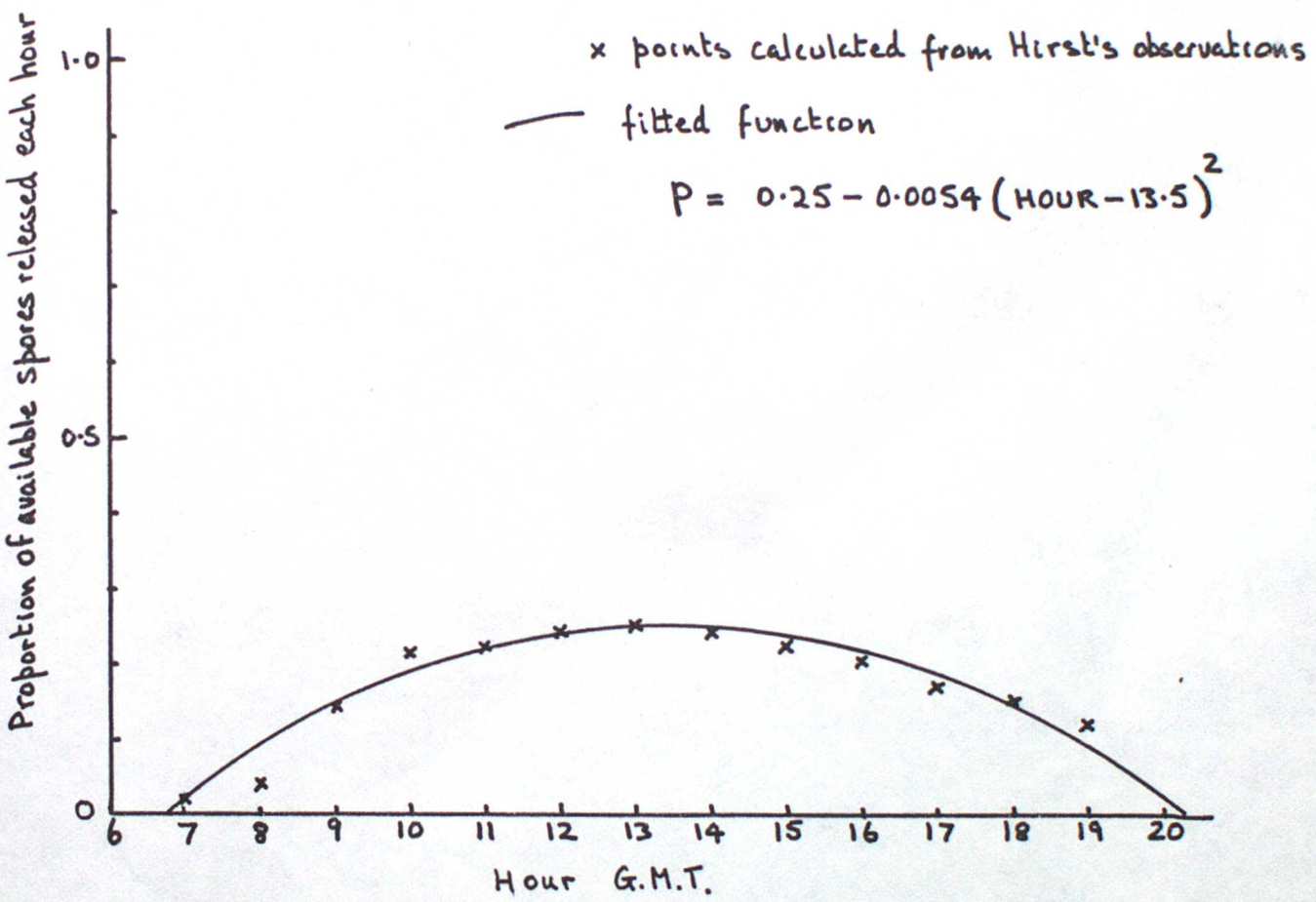
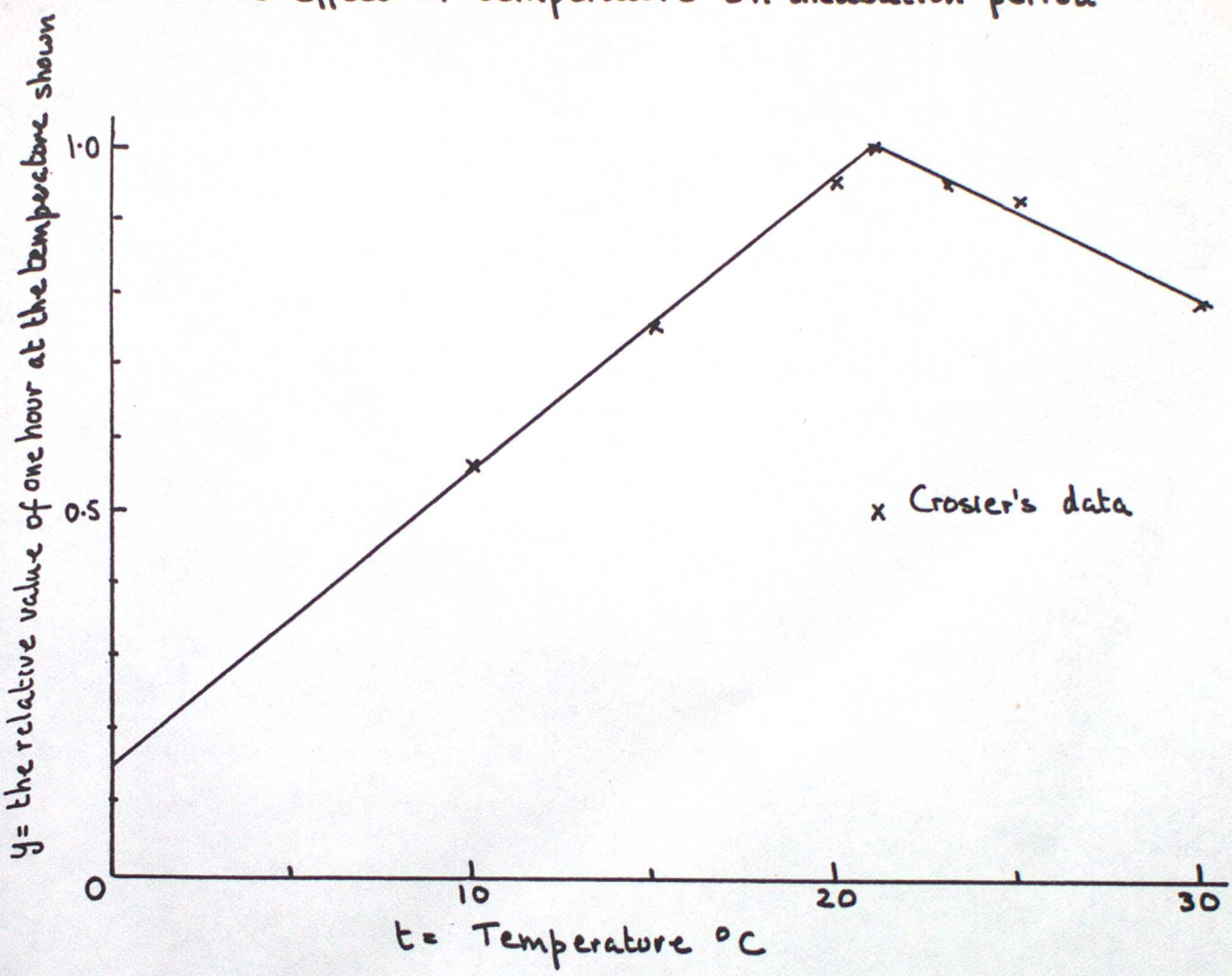


Figure 5

The effect of temperature on incubation period

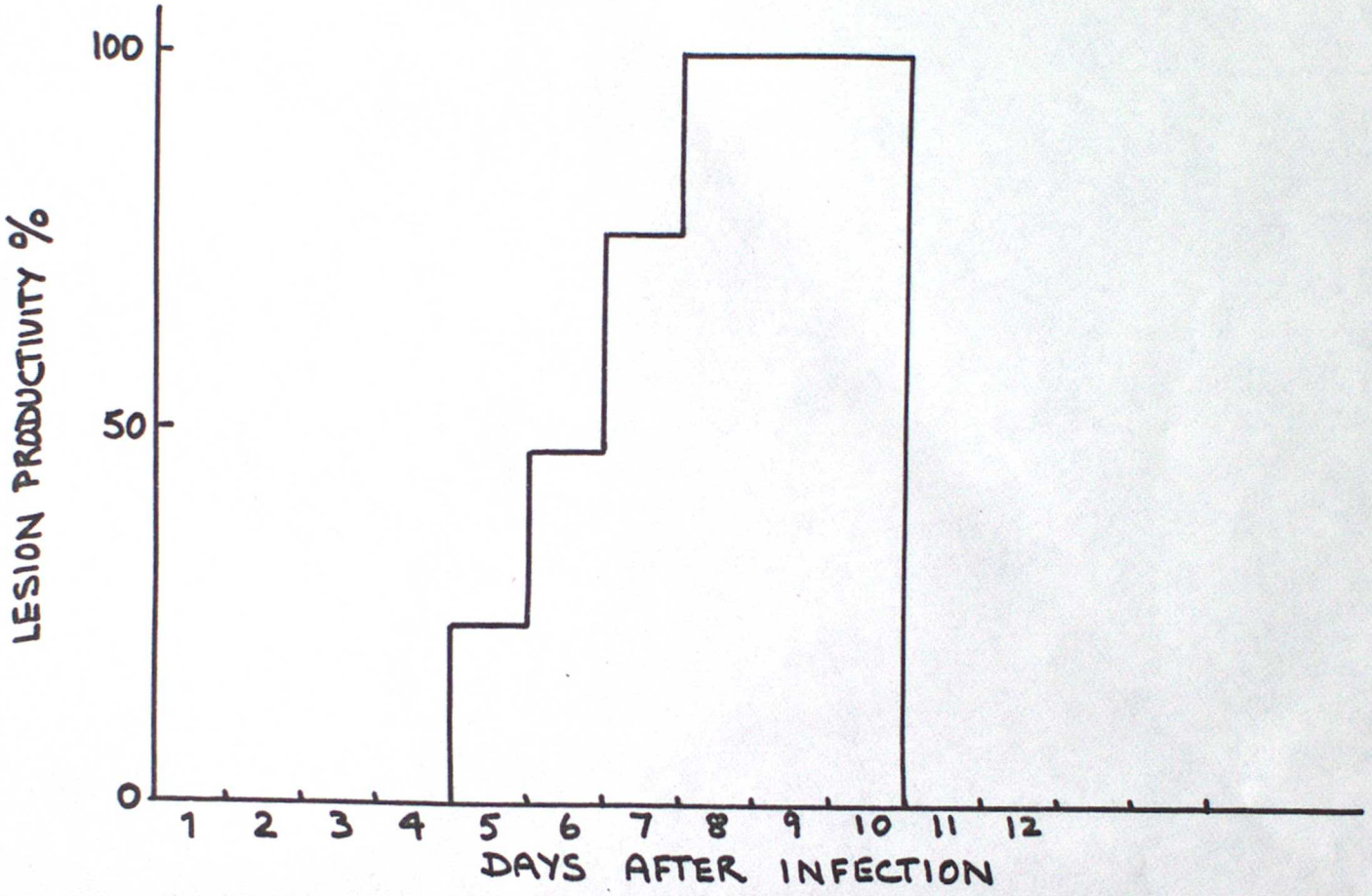


For $t \leq 21$ $y = 0.16 + 0.04t$

For $t > 21$ $y = 1 - 0.023(t-21)$

Figure 6

POTENTIAL SPORE PRODUCTION BY A DEVELOPING LESION



FLOW CHART FOR BLIGHT

Figure 7a

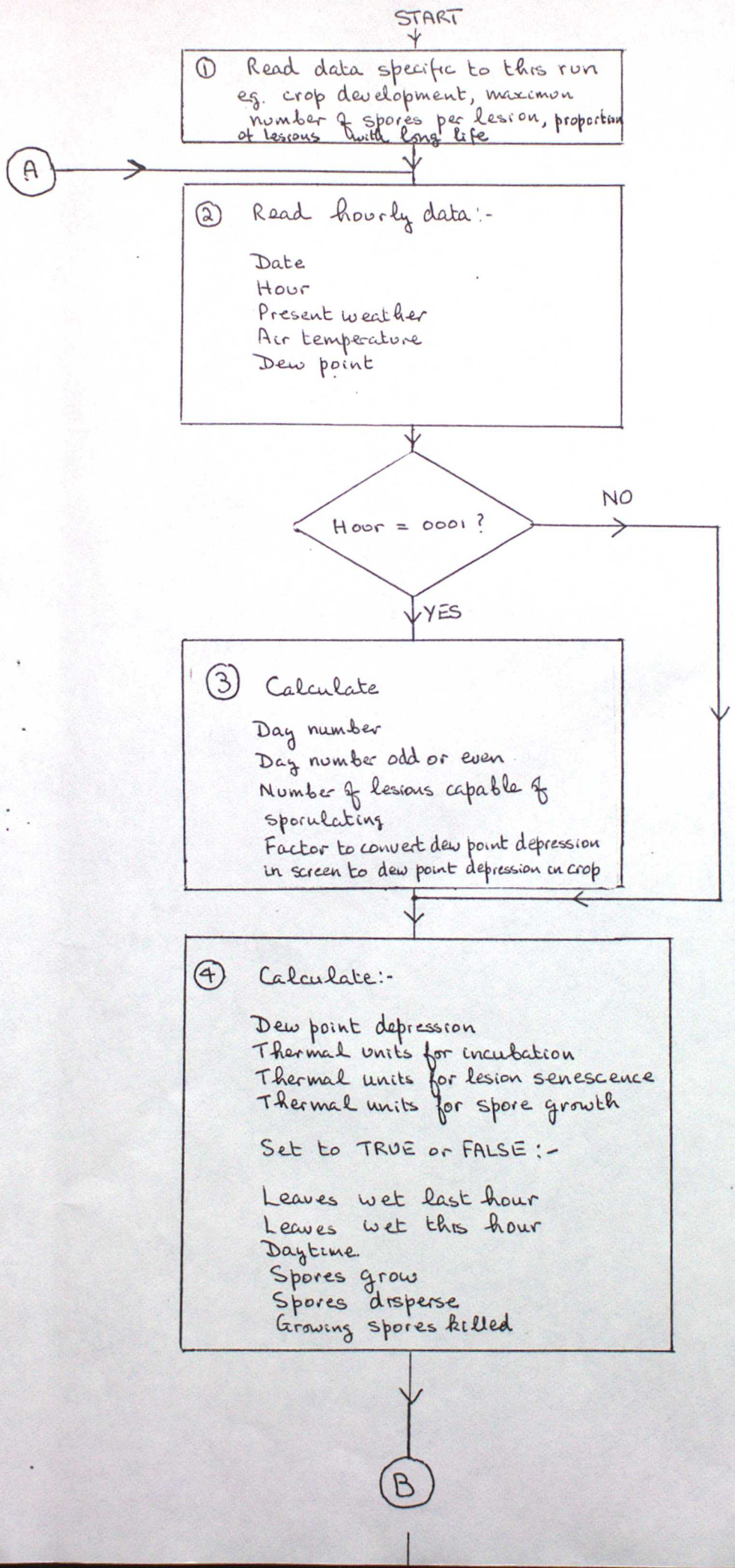


Figure 7b

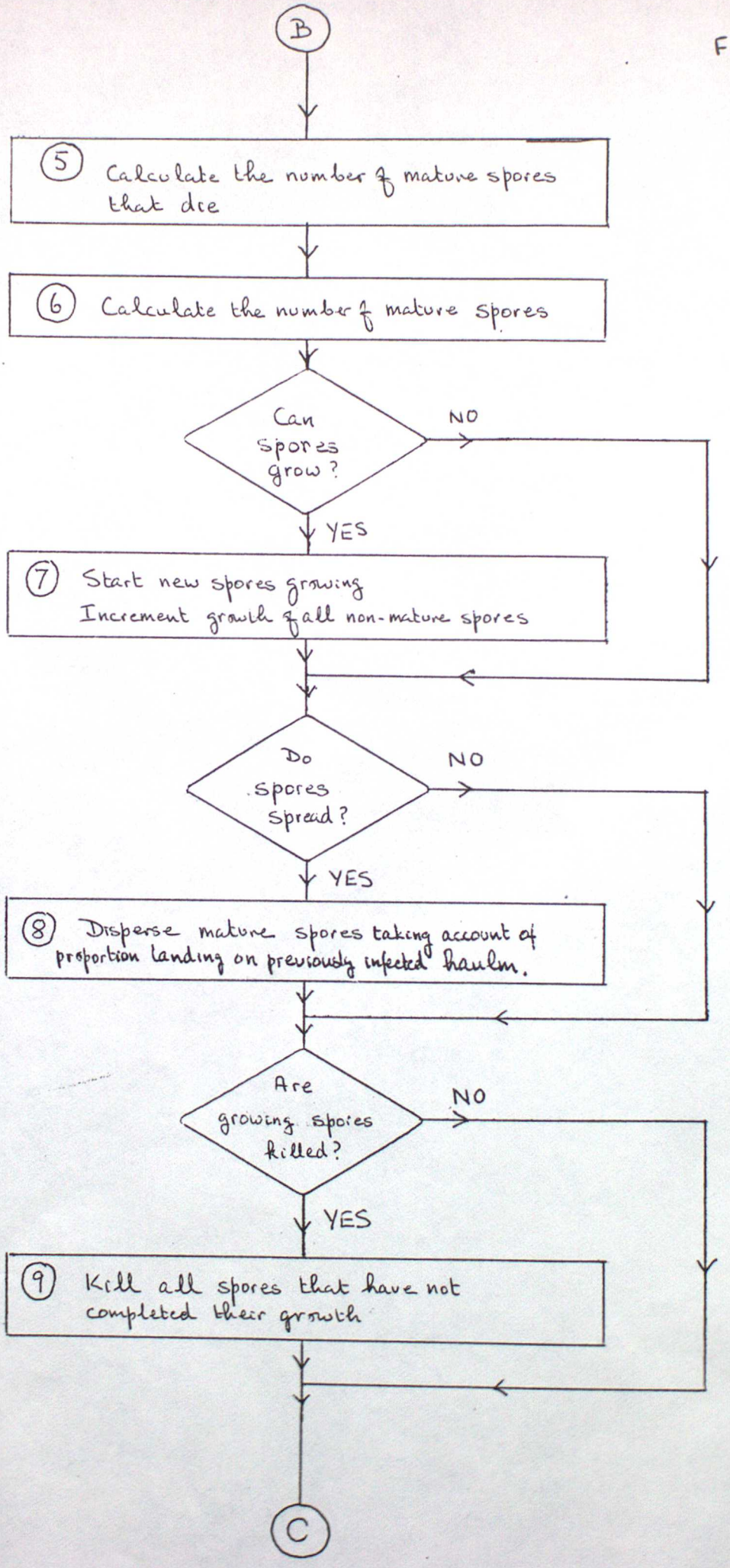

B
5 Calculate the number of mature spores that die
6 Calculate the number of mature spores
Can spores grow?
NO
YES
7 Start new spores growing
Increment growth of all non-mature spores
Do spores spread?
NO
YES
8 Disperse mature spores taking account of proportion landing on previously infected haulm.
Are growing spores killed?
NO
YES
9 Kill all spores that have not completed their growth
C

Figure 7c

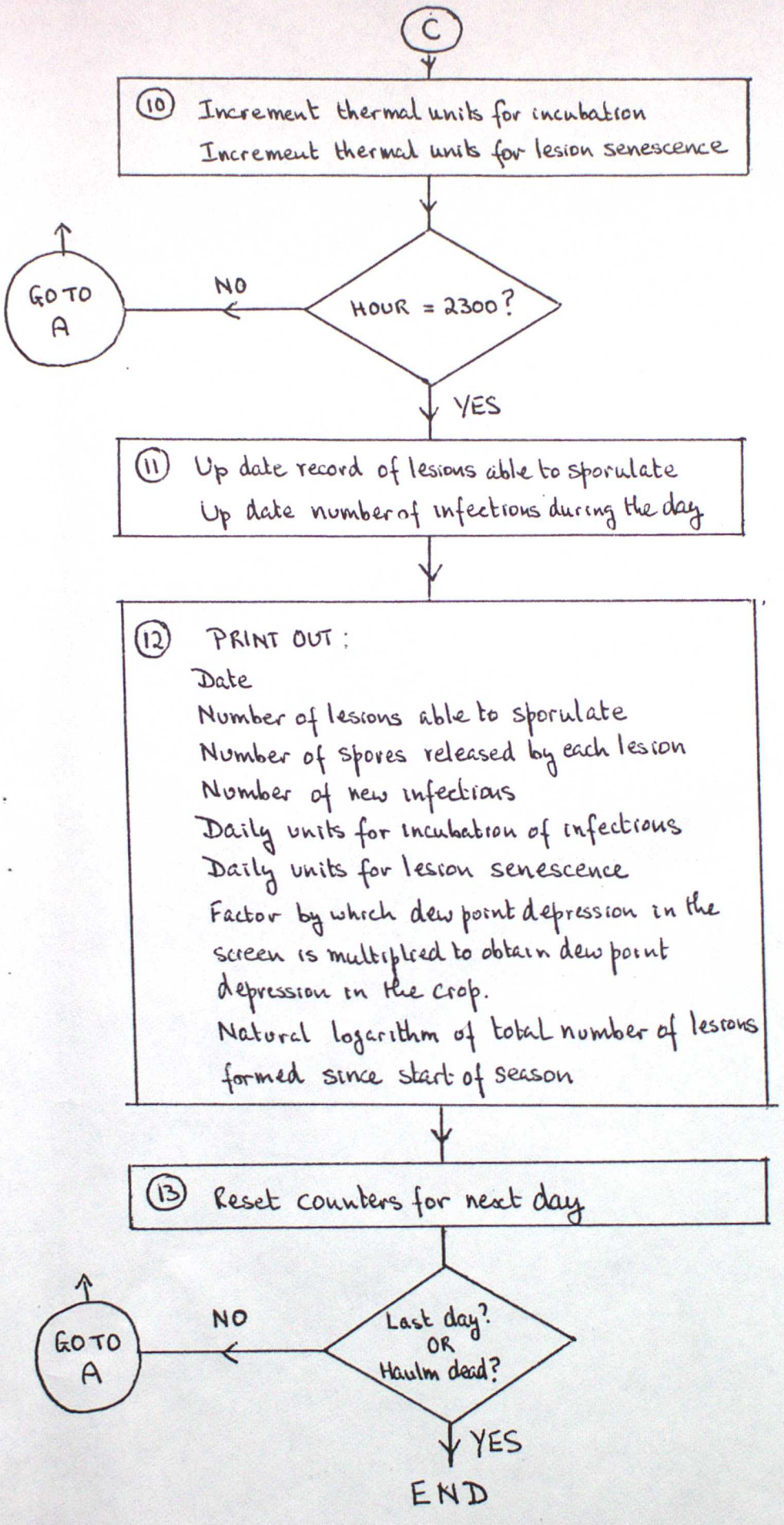

C
10 Increment thermal units for incubation
Increment thermal units for lesion senescence
HOUR = 2300?
NO
GO TO A
YES
11 Up date record of lesions able to sporulate
Up date number of infections during the day
12 PRINT OUT:
Date
Number of lesions able to sporulate
Number of spores released by each lesion
Number of new infections
Daily units for incubation of infections
Daily units for lesion senescence
Factor by which dew point depression in the screen is multiplied to obtain dew point depression in the crop.
Natural logarithm of total number of lesions formed since start of season
13 Reset counters for next day
Last day? OR Haulm dead?
NO
GO TO A
YES
END

Figure 8a

STATION ELMDCN
INCCULUM 1
MAXSPL 300MAXLE2000000000STEM 0.1000000

DAY	MONTH	YEAR	LESPOR	JSPORE	INFECT	FDPD	LN(L)
15	5	1978	1	0	0	1.00000	0.0
16	5	1978	1	0	0	1.00000	0.0
17	5	1978	1	0	0	1.00000	0.0
18	5	1978	1	0	0	1.00000	0.0
19	5	1978	1	0	0	1.00000	0.0
20	5	1978	1	0	0	1.00000	0.0
21	5	1978	1	0	0	1.00000	0.0
22	5	1978	1	0	0	1.00000	0.0
23	5	1978	1	0	0	1.00000	0.0
24	5	1978	1	0	0	1.00000	0.0
25	5	1978	1	0	0	1.00000	0.0
26	5	1978	1	0	0	1.00000	0.0
27	5	1978	1	0	0	1.00000	0.0
28	5	1978	1	0	0	1.00000	0.0
29	5	1978	1	0	0	1.00000	0.0
30	5	1978	1	0	0	1.00000	0.0
31	5	1978	1	0	0	1.00000	0.0
1	6	1978	1	0	0	1.00000	0.0
2	6	1978	1	26	2	1.00000	0.0
3	6	1978	1	0	0	1.00000	0.0
4	6	1978	1	0	0	1.00000	0.0
5	6	1978	1	0	0	1.00000	0.0
6	6	1978	1	0	0	1.00000	0.0
7	6	1978	1	0	0	1.00000	0.0
8	6	1978	1	10	1	1.00000	0.0
9	6	1978	1	0	0	1.00000	0.69
10	6	1978	2	0	0	1.00000	0.69
11	6	1978	2	0	0	1.00000	1.10
12	6	1978	3	0	0	1.00000	1.10
13	6	1978	3	0	0	0.90000	1.10
14	6	1978	3	0	0	0.90000	1.10
15	6	1978	3	0	0	0.90000	1.10
16	6	1978	3	153	45	0.90000	1.10
17	6	1978	3	0	0	0.90000	1.10
18	6	1978	3	0	0	0.90000	1.10
19	6	1978	1	0	0	0.90000	1.39
20	6	1978	2	0	0	0.90000	1.39
21	6	1978	2	0	0	0.90000	2.30
22	6	1978	8	56	40	0.90000	2.94
23	6	1978	17	0	0	0.90000	3.33
24	6	1978	26	0	0	0.90000	3.58
25	6	1978	34	0	0	0.90000	3.81
26	6	1978	43	0	0	0.90000	3.89
27	6	1978	47	0	0	0.90000	3.89
28	6	1978	47	0	0	0.90000	4.06
29	6	1978	55	108	550	0.90000	4.22
30	6	1978	24	0	0	0.90000	4.33
1	7	1978	32	0	0	0.75000	4.44
2	7	1978	41	176	696	0.75000	4.49
3	7	1978	45	25	89	0.75000	4.49
4	7	1978	45	17	44	0.75000	4.91
5	7	1978	92	19	91	0.75000	5.51
6	7	1978	203	0	0	0.75000	5.88
7	7	1978	277	0	0	0.75000	6.20
8	7	1978	411	0	0	0.75000	6.66

For key see Figure 8c

Figure 3b

9	7	1978	697	62	4181	0.75000	6.92
10	7	1978	934	0	0	0.75000	7.09
11	7	1978	1122	0	0	0.75000	7.25
12	7	1978	1328	0	0	0.75000	7.32
13	7	1978	932	0	0	0.75000	7.34
14	7	1978	968	0	0	0.75000	7.80
15	7	1978	1231	0	0	0.75000	8.14
16	7	1978	2160	0	0	0.75000	8.40
17	7	1978	3117	0	0	0.75000	8.61
18	7	1978	4086	0	0	0.75000	8.66
19	7	1978	4335	0	0	0.50000	8.66
20	7	1978	4335	0	0	0.50000	8.66
21	7	1978	4335	0	0	0.50000	8.66
22	7	1978	572	0	0	0.50000	8.66
23	7	1978	572	114	6291	0.50000	8.66
24	7	1978	572	81	4575	0.50000	8.66
25	7	1978	572	0	0	0.50000	8.66
26	7	1978	572	0	0	0.50000	8.66
27	7	1978	572	0	0	0.50000	8.67
28	7	1978	633	48	2531	0.50000	8.96
29	7	1978	2613	0	0	0.50000	9.28
30	7	1978	5513	126	66155	0.50000	9.51
31	7	1978	8297	101	82966	0.50000	9.66
1	8	1978	10541	186	189722	0.50000	9.72
2	8	1978	11492	0	0	0.50000	9.76
3	8	1978	12111	214	254285	0.50000	9.79
4	8	1978	7063	51	35304	0.50000	10.45
5	8	1978	19447	69	116644	0.50000	11.18
6	8	1978	57017	0	0	0.50000	11.90
7	8	1978	132696	0	0	0.50000	12.35
8	8	1978	215300	24	430435	0.50000	12.74
9	8	1978	325562	203	6496718	0.50000	13.02
10	8	1978	436026	46	1737396	0.50000	13.23
11	8	1978	539534	0	0	0.50000	13.39
12	8	1978	639305	0	0	0.50000	13.48
13	8	1978	565730	0	0	0.50000	13.63
14	8	1978	677131	125	8070862	0.50000	14.65
15	8	1978	1970751	0	0	0.50000	15.30
16	8	1978	3851348	0	0	0.50000	15.69
17	8	1978	5930469	0	0	0.50000	15.95
18	8	1978	7787242	0	0	0.50000	16.05
19	8	1978	8658003	0	0	0.50000	16.24
20	8	1978	10621740	0	0	0.50000	16.41
21	8	1978	12307354	0	0	0.50000	16.56
22	8	1978	8568176	61	50309856	0.50000	16.68
23	8	1978	9013731	0	0	0.50000	16.68
24	8	1978	9013731	0	0	0.50000	16.68
25	8	1978	9013731	0	0	0.50000	16.68
26	8	1978	9013731	0	0	0.50000	16.68
27	8	1978	1749955	0	0	0.50000	17.06
28	8	1978	9850001	15	9492683	0.50000	17.46
29	8	1978	22412579	0	0	0.50000	17.72
30	8	1978	34076307	0	0	0.50000	17.92
31	8	1978	44929683	0	0	0.50000	18.03
1	9	1978	52059811	74	320269568	0.50000	18.03
2	9	1978	52059811	0	0	0.50000	18.04
3	9	1978	52570040	0	0	0.50000	18.07
4	9	1978	54550063	0	0	0.50000	18.10
5	9	1978	11308424	0	0	0.50000	18.13
6	9	1978	13438302	175	172971296	0.50000	18.49

For key see figure 8c

Figure 8c

7	9	1978	45922337	183	483923712	0.50000	19.05
8	9	1978	126117688	0	0	0.50000	19.40
9	9	1978	204706888	24	175031264	0.50000	19.67
10	9	1978	287583192	0	0	0.50000	19.82
11	9	1978	336872966	0	0	0.50000	19.98
12	9	1978	406587153	0	0	0.50000	20.26
13	9	1978	560421409	0	0	0.50000	20.51
14	9	1978	453857259	0	0	0.50000	20.72
15	9	1978	639232768	0	0	0.50000	20.86
16	9	1978	788356768	0	0	0.50000	20.90
17	9	1978	832473568	0	0	0.50000	20.93
18	9	1978	714334992	0	0	0.50000	20.93
19	9	1978	716009264	0	0	0.50000	20.93
20	9	1978	28047792C	0	0	0.50000	20.93
21	9	1978	280477920	0	0	0.50000	20.93
22	9	1978	122949776	0	0	0.50000	20.93
23	9	1978	122949776	0	0	0.50000	20.93
24	9	1978	122949776	0	0	0.50000	20.93
25	9	1978	122949776	0	0	0.50000	20.93
26	9	1978	122949776	0	0	0.50000	20.93
27	9	1978	122949776	0	0	0.50000	20.93
28	9	1978	122949776	0	0	0.50000	20.93
29	9	1978	122949776	10	45939984	0.50000	20.93
30	9	1978	122949776	0	0	0.50000	20.93

MAXSPL = maximum number of spores that can grow on a lesion

MAXLE = number of lesions needed to destroy haulm

STEM = proportion of lesions with extended lives

LESPOR = number of lesions able to produce spores

JSPORE = number of spores produced by each active lesion

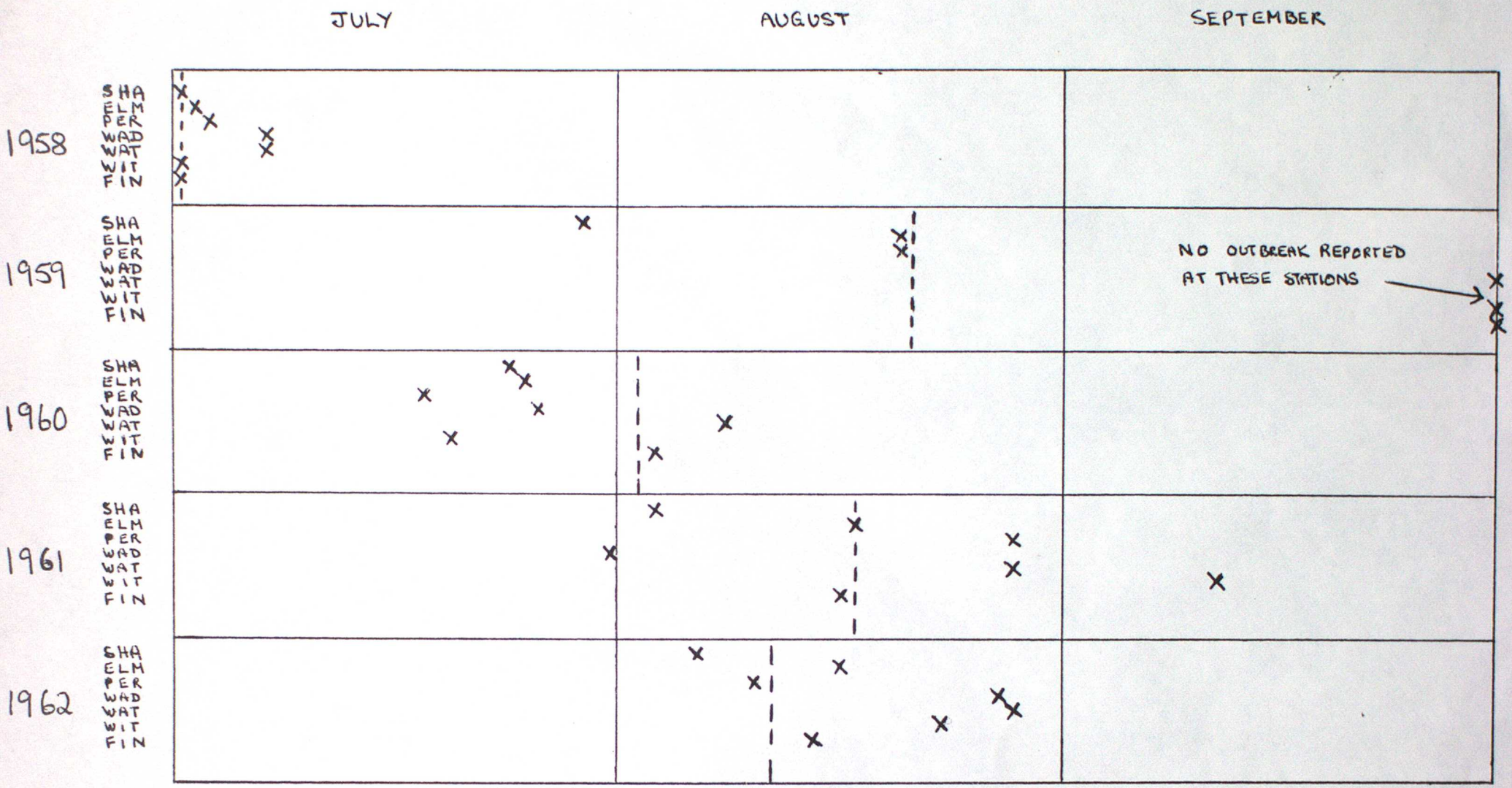
INFECT = number of new infections

FDPD = factor by which dew point depression in the screen is multiplied to obtain dew point depression in the crop

LN(L) = natural logarithm of the total number of lesions formed since the start of the season.

Figure 9

OUTBREAK DATES OF POTATO BLIGHT IN THE MIDLANDS



SHA = SHAWBURY
ELM = ELMDON
PER = PERSHORE
WAD = WADDINGTON
WAT = WATNALL
WIT = WITTERING
FIN = FINNINGLY

X = DATE OF REPORTED OUTBREAK

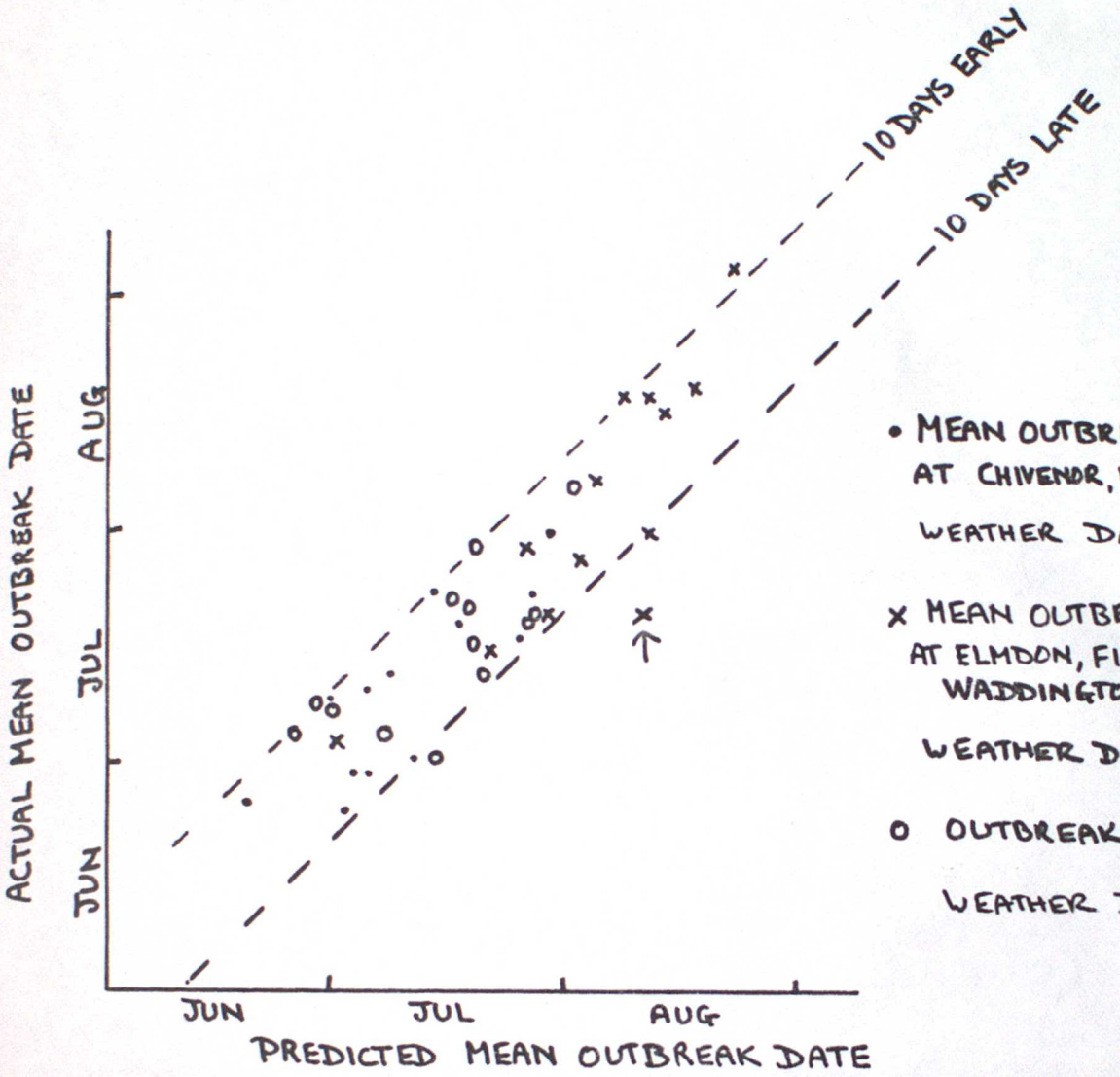
= DATE OF OUTBREAK CALCULATED BY BLIGHT

Figure 10

Figure 10

COMPARISON OF PREDICTED AND ACTUAL OUTBREAK DATES OF POTATO BLIGHT

(1958-1970)



• MEAN OUTBREAK DATES
AT CHIVENOR, EXETER, PLYMOUTH & ST MAWGAN
WEATHER DATA FROM PLYMOUTH

× MEAN OUTBREAK DATES
AT ELMDON, FINNIGLY, PERSHORE, SHAWBURY
WADDINGTON WATNALL & WITTERING
WEATHER DATA FROM WADDINGTON & ELMDON

o OUTBREAK DATE AT VALLEY
WEATHER DATA FROM VALLEY

Figure 11

CALCULATED DEVELOPMENT OF POTATO BLIGHT 1966

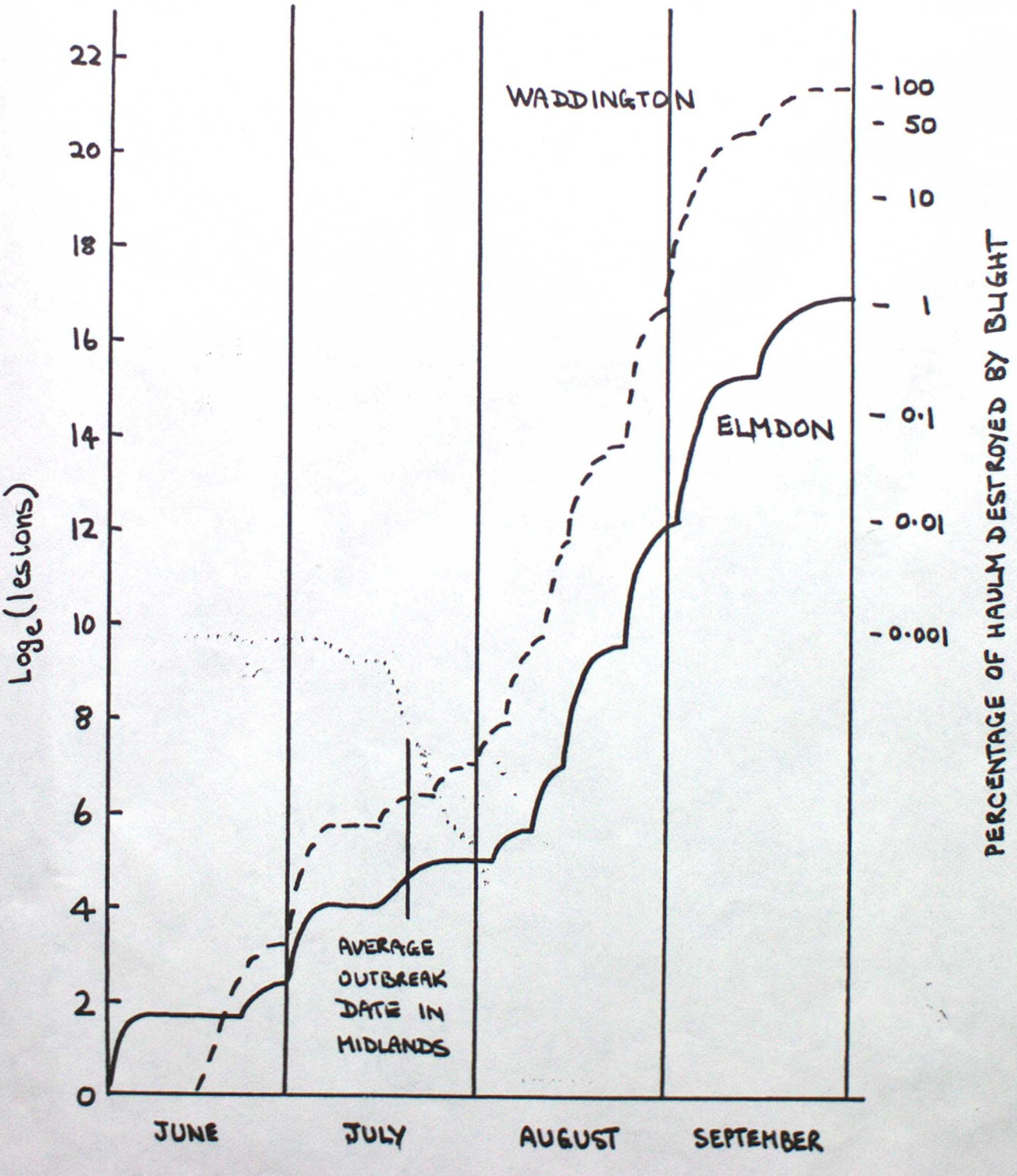


Figure 12

CALCULATED DEVELOPMENT OF POTATO BLIGHT

WADDINGTON

—— STEM = 1·0

- - - STEM = 0·0

····· STEM = 0·1

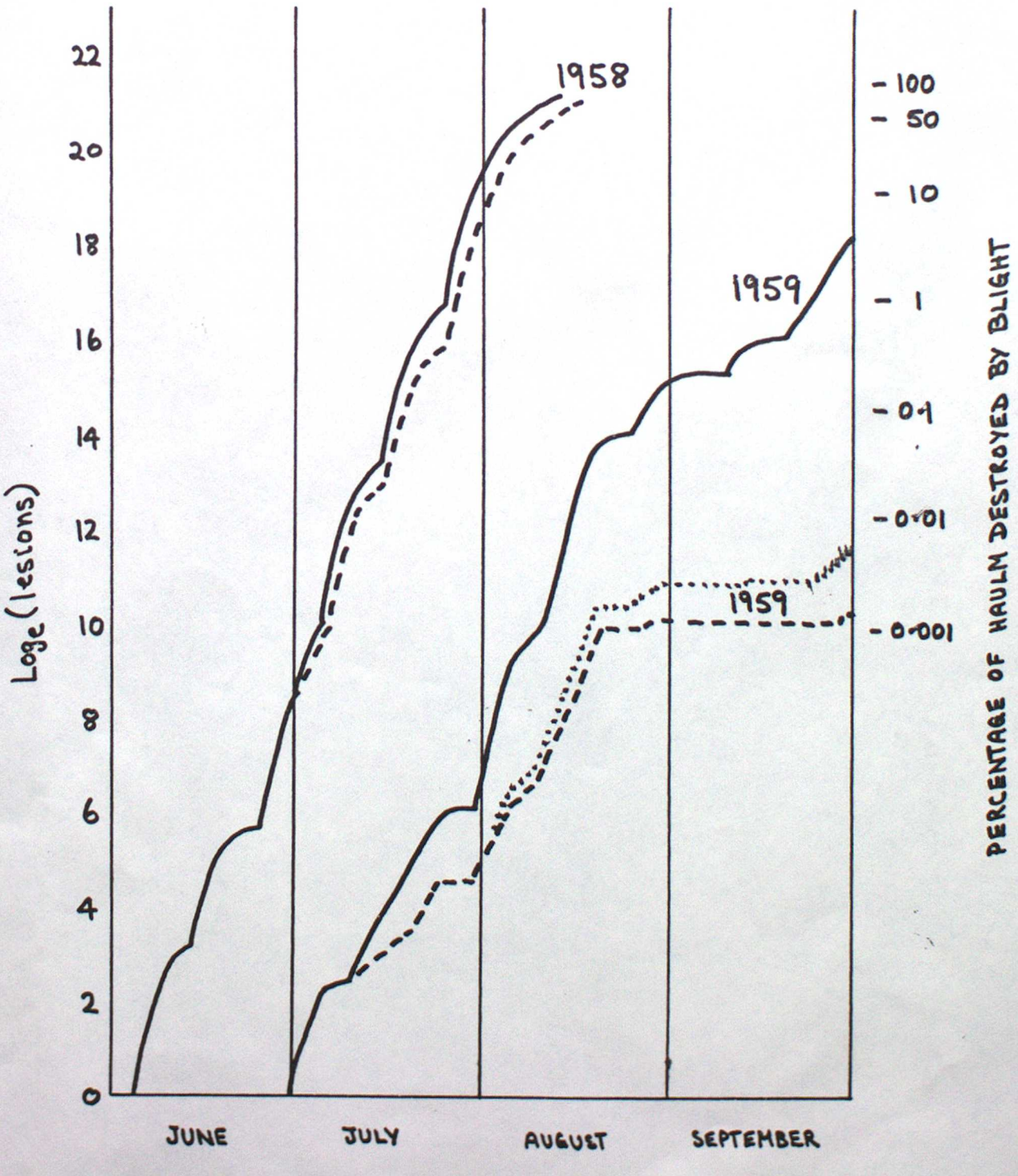


Figure 13

CALCULATED DEVELOPMENT OF POTATO BLIGHT

ELMDON 1978

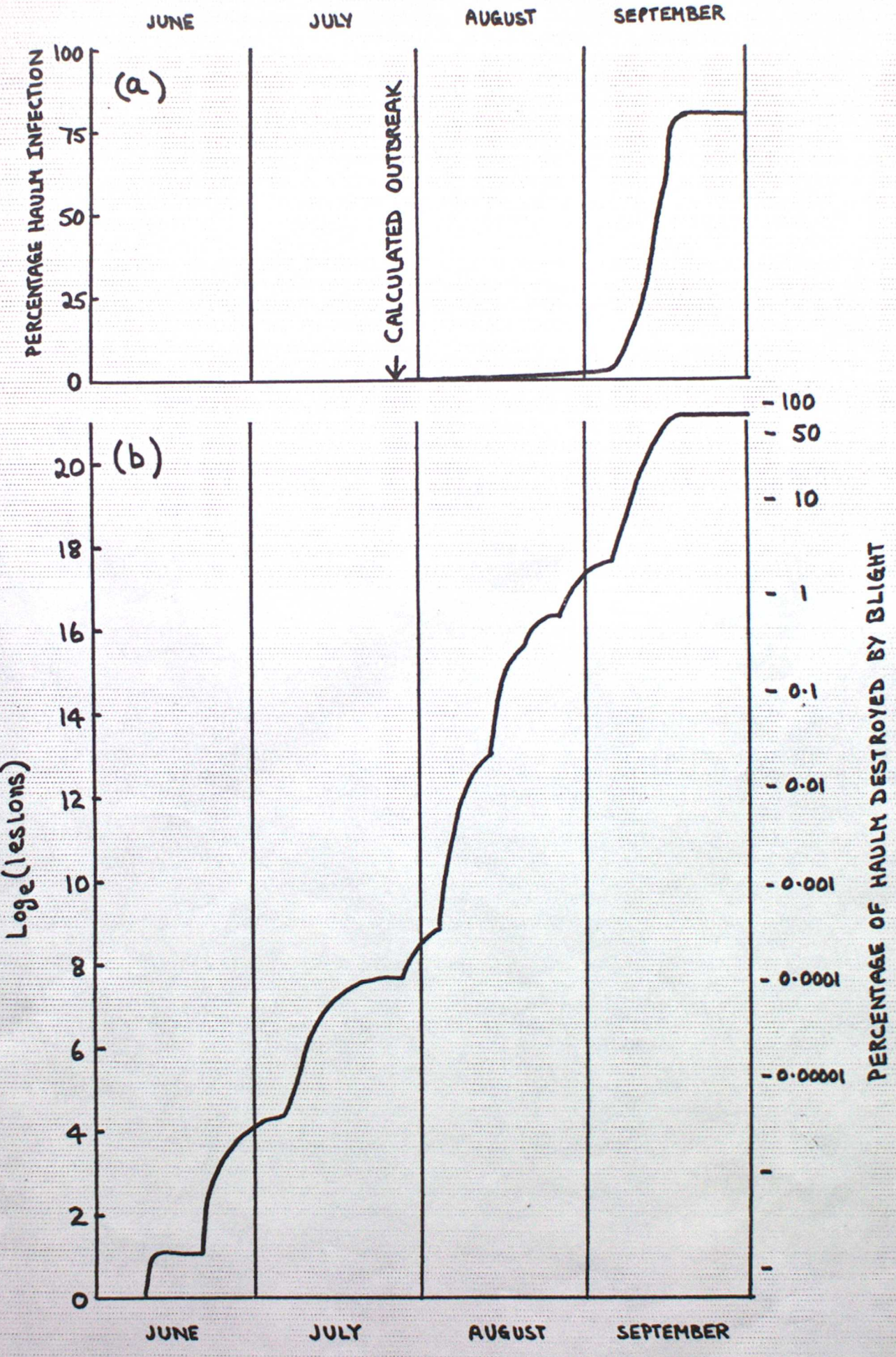


Figure 14

AGRICULTURAL DEVELOPMENT AND ADVISORY SERVICE

Potato Blight on the Haulm — Key No. 2·1·1

Phytophthora infestans (Mont.) de Bary

Blight %	
0	Not seen on field.
0.1	Only a few plants affected here and there: up to 1 or 2 spots in 12 yards radius.
1	Up to 10 spots per plant, or general light spotting.
5	About 50 spots per plant or up to 1 leaflet in 10 attacked.
25	Nearly every leaflet with lesions, plants still retaining normal form: field may smell of blight, but looks green although every plant is affected.
50	Every plant affected and about ½ of leaf area destroyed by blight: field looks green flecked with brown.
75	About ¼ of leaf area destroyed by blight: field looks neither predominantly brown or green. In some varieties the youngest leaves escape infection so that green is more conspicuous than in varieties like King Edward, which commonly shows severe shoot infection
95	Only a few leaves left green, but stems green.
100	All leaves dead, stems dead or dying.

In the earlier stages of a blight epidemic parts of the field sometimes show more advanced decay than the rest and this is often associated with the primary foci of the disease. Records may then be made as, say 1 + pf 25, where pf 25 means 25% in the area of the primary foci.

Note:

Make successive assessments at intervals of 7 to 14 days to record progress of blight. Begin in good time as both nil and starting date records (0.1%) are important. Difficulties in judging allowance to be made for stem-blight on a particular date are overcome by making another assessment later.